Part V

Cost Summary

Chapter 18

Cost Summary

This proposal is accompanied by a detailed Work Breakdown Structure (WBS) and cost estimate, which includes several hundred pages of material. In this section of the proposal, we explain briefly the methods used and present the high level summary (rollup) of the cost estimate.

18.1 Methodology

The BTeV collaboration has prepared a detailed costing of the proposal following procedures prepared by E. Barsotti (entitled 'Cost & Schedule Procedures for the BTeV Proposal'). The procedures document is based on the procedures developed for the SDC collaboration (see SDC document SDT-000009). These procedures are currently being used for US CMS projects.

18.1.1 Documentation

The proposed BTeV costs are documented in a Work Breakdown Structure (WBS) Excel spreadsheet. The WBS spreadsheet is accompanied by two Microsoft Word documents, the WBS Level 2 System Summaries, and the WBS dictionary. All three documents are available on a BTeV website.

18.1.2 Inclusivity

We tried to include all the essential elements of the detector, the electronics, the trigger and the data acquisition system and all infrastructure required to carry out a project of this size and complexity. We used recent experience to try to avoid omissions which have led to problems for other projects in the past. In particular, based on discussion with electronics engineers, we have included an appropriate number of prototype development runs on the electronics development projects. We have also included large contingencies on these runs since they sometimes go awry. We have costs for a reasonble number of test stands to support

R&D activities and testing at multiple sites. There are significant resources assigned to project management and ES&H both for the whole project and for each subproject. We have included all calibration and monitoring systems and many infrastructure items which are commonly overlooked such as control room electronics. The data acquisition and trigger software are also included in the construction project since the detector can not be shown to be working without them.

While it has been traditional (BaBar being a recent exception) to treat the offline computing as a separate entity, we at least wanted to describe the resources needed for it. We have included it in our WBS but have split it out into a separate cost table. The estimates for hardware at this point should be viewed as approximately correct. The estimates for resources to develop software are diffficult to make and should be viewed as informed guesses based on recent experience.

18.1.3 Labor Costs

We have followed the rule of accounting for the effort of collaboration physicists but not costing it. It is considered part of the 'base program' cost.

We have costed all engineers and lead technicians at Fermilab rates. Where we plan to use less skilled technicians, student, or term labor, we have used a lower rate. These are called out clearly in the spreadsheets. It should be noted that software professionals and computer scientists are treated under the engineer category.

All labor is split into development and manufacturing. For salaries, we include fringe benefits for all labor except term labor. We do not include overhead.

18.1.4 Handling of Inflation and Deflation

To handle the effects of inflation on personnel costs, we assume that the average year for development is 2002 and inflate all personnel costs to that year. We assume that the average year for production manufacturing is 2004 and inflate all personnel costs to that year.

Most major cost drivers involve discussions with vendors. We have tried to make clear to them when the main acquisitions would be made and have asked for prices applicable during that period. Since their responses are only quotes, not committments, it is very hard for us to do more than this.

Many high technology components undergo deflation at least on a price/performance basis. We have used standard trending practices in each industry to estimate the costs of CPUs, disks, computer memory, FPGAs, optical links, network switches, etc. Many of these items are purchased late in the BTeV construction period. We have been fairly conservative in the trending lines we have used.

18.1.5 Contingency

For most WBS elements we have used the formula provided in the handbook. This has led to a consistent picture of contingency but may appear to be low. We believe that this is because the plan emphasizes so many costed R&D steps whose main goal is to reduce risk. We have also been fairly conservative in trending the cost of electronics and computer costs into future years. Thus, there exists the equivalent of additional hidden contingency in the number of design cycles provided, and in the trending curves used.

18.2 The Detector Cost Estimate

Since BTeV is only at the proposal submission stage, we do not have complete engineering designs for our systems. However, we have a stable and complete baseline design and an active program of R&D on all parts of the detector. Many of our systems are similar to ones that have been built recently or are being built for future experiments. We have drawn on our own experience with these types of systems, and that of others, to develop the cost estimate for BTeV. In many cases, the large cost drivers are procurements and, for these, we have had direct discussions with vendors and have obtained price quotes.

Below, we describe briefly the basis of the cost estimate for each major WBS Level 2 project. We break it into two parts: the first describes the tasks associated with the construction of the detector, including the hardware and software for the trigger and data acquisition; the second describes costs associated with providing facilities to carry out the offline analysis and to develop the offline framework and analysis programs. More details can be found in the accompanying WBS Spreadsheet and Dictionary entries (note, the subsection numbers here correspond to the Level 2 WBS cost estimate sections).

18.2.1 Vertex and Toroidal Magnets and Beam Pipe

This section covers the three major mechanical subsystems of the proposed BTeV spectrometer. They are the vertex analysis magnet, the four toroidally magnetized iron absorber walls for the muon detectors, and the beam pipes necessary to connect the silicon pixel detector vacuum box to the rest of the Tevatron accelerator.

The vertex magnet will be obtained by reusing the existing SM3 analysis magnet from experiment E866 in the MEast beam line. The muon toroids (and their shielding insert) will be assembled from large soft-iron slabs machined on two sides only. The silicon vacuum box to beampipe transition window will be a 0.030" thick, hemispherical, spun aluminum transition piece. The beampipes will be thin-walled, 3.8 or 6.4 cm diameter aluminum beam pipes.

The rigging costs and the assembly and manufacturing techniques involved here are standard and well understood at Fermilab. The mechanical costs include $470K for the vertex magnet, $1.14M for the 4 magnetized muon toroids, $32K for the beam pipes, and $160K for ES&H and management.

18.2.2 Pixel Detector

The pixel vertex detector provides high resolution space points near the interaction that are used both online and offline to reconstruct tracks and associate them with their parent vertices. The pixel sensors will be very similar to those developed for use in the ATLAS pixel detector. They will be fabricated with n+ pixels (50 x 400 micron cell size) on low resistivity n-bulk silicon. An Application Specific Integrated Circuit (ASIC) being designed at Fermilab (FPIX) will read out the pixel sensors. A non-radiation hard prototype of this chip has performed very well in recent beam tests. We plan to implement the final version in a commercial process, 0.25 μm CMOS, which appears to be capable of withstanding the radiation dose. The pixel sensors will be connected to the readout chips using bump-bonding technology. The mechanical supports will be all-carbon composite structures that will include integrated cooling tubes. These structures will be developed and manufactured by Energy Science Laboratories, Inc. A relatively high contingency is assigned to this item. This contingency is intended to cover the possibility that all-carbon structures cannot be successfully developed, and beryllium support and cooling frames must be used instead.

The costs of the pixel detector are based on: our own experience developed during the R&D phase, which includes extensive interaction with vendors, experience in building silicon strips for Run II, knowledge of the cost estimates of the LHC experiments CMS and ATLAS, and engineering input on production issues (SCIdet) and electronics design (front end and data acquisition). These costs include \$2.9M for the sensors, \$4.0M for the front-end electronics, \$2.0M for mechanical systems, \$570K for test beam studies, and \$520K for ES&H and management.

18.2.3 RICH Detector

The purpose of the BTeV Ring Imaging Cerenkov Detectors (RICH) is to provide good and efficient identification of hadrons with momentum from a few GeV/c to over 70 GeV/c. A main cost driver has been the sensors, which are Hybrid Photo Diodes (HPD).

The price of the HPDs is based on discussions with the vendor, DEP. The cost of the readout is based on our collaborator's recent experience in developing a similar readout for the CLEO RICH in collaboration with a vendor. Cost of the high voltage units has been obtained by discussions with CAEN. Costs for mirrors, mounts, gas vessel etc were derived with the help of the experience of HERA-B. The RICH costs include \$11.2M for the photon detectors, \$2.6M for electronics, \$2.2M for mechanical systems, and \$620K for ES&H and management.

18.2.4 Electromagnetic Calorimeter Detector

The BTeV electromagnetic calorimeters (ECAL) are designed to detect and measure the energy of electrons and photons by total absorption of their resulting electromagnetic showers in a highly segmented array of $PbWO_4$ crystals. Each crystal is read out with a photomultiplier tube (PMT).

The costs of crystal production were obtained by direct discussion with vendors in Russia and China who are making the nearly identical CMS crystals and with other potential suppliers. Costs for other items were derived from: discussions with a PMT vendor (Hamamatsu), quotes on high voltage systems from CAEN, discussions about the mechanical support with BaBar and CMS, and discussions about the calibration system with KTeV/KAMI and CMS. The ECAL costs include $15.0M for the crystals, $3.4M for electronics, $1.6M for mechanical systems, $490K for testing, and $500K for ES&H and management.

18.2.5 Muon Detector

The BTeV muon detectors are an array of 3/8" proportional tubes positioned between and behind the muon toroids. The basic building blocks of the detector are "planks" of thirty-two proportional tubes arranged in a double layer with an offset of half a tube. Each set of tubes is soldered at each end to a brass gas manifold, and supported in the middle by soldering to a brass rib piece. The electronics is based on a chip used in the Run-II CDF central outer tracker. Prototype chambers have been operated in a test beam at Fermilab and have resulted in design modifications to the electronics. The design of this system is viewed as nearly complete.

Costs of the muon system, based on the current design, are derived from detailed discussions with vendors and pricing of all components. The costs include $2.7M for the proportional tubes, $3.0M for electronics, $80K for mechanical systems, $320K for test beam studies, and $420K for ES&H and management.

18.2.6 Forward Tracker Straw Detector

The straw tube tracker consists of 7 stations of straw tube proportional wire detectors in each BTeV spectrometer arm with a total of some 86,000 individual straw tube detectors. The design and construction of the straw tubes closely follows the design of the ATLAS TRT straw tubes currently under construction at a BTeV collaborator's university.

The costs of the straw tube system are derived from the very detailed cost baseline of the ATLAS detector. The costs include $6.5M for the straw detectors, $4.2M for electronics, $320K for mechanical systems, $300K for test beam studies, and $600K for ES&H and management.

18.2.7 Forward Tracker Silicon Microstrip Detector

The Forward Tracker Silicon Microstrip Detector consists of a set of small angle silicon microstrip detectors. The silicon planes will be constructed from single sided silicon wafers, of dimension 12 cm x 4.8 cm and 4.8 cm x 9 cm, and thickness 200 microns. The silicon front end electronics will require several custom designed integrated circuits.

The costs of the silicon system are derived from the costs of building the Run II CDF silicon detectors at SCIDET. Members of the BTeV group have also built similar systems.

The costs include \$1.1M for the silicon detectors, \$2.2M for electronics, \$430K for mechanical systems, \$400K for test beam studies, and \$660K for ES&H and management.

18.2.8 Unassigned

WBS level 1.8 is unassigned

18.2.9 Level 1 and Global Triggers

The Level 1 vertex trigger uses the pixel detecetor to search for decay vertices in every beam crossing (7.6 MHz) and provides the basic trigger for the experiment. A major R&D effort has developed the algorithms and carried out the timing studies required to establish the initial design and size of this system. The Level 1 trigger also includes a dimuon trigger from the muon system, and other prescale and beam crossing triggers. The triggers process data stored in hit lists in fast memory. The algorithms and trigger decisions are implemented in field-programmable gate arrays (FPGA) and digital signal processors (DSP). The Global Level 1 Trigger (GLV1) controls the flow of data from the front-end detector electronic subsystems into the data acquisition system. Monitoring of the rates, luminosity, etc. are also done in this unit.

We recognize that rapid progress in electronics implies that the present design DSPs, FPGAs, fast memory, etc., will be superseded by devices with greater performance per dollar. We have attempted to estimate these trends in costing the trigger system. The costs of the Level 1 and Global Trigger include \$4.8M for the vertex trigger system, \$1.1M for the muon trigger system, \$270K for the GLV1 and other trigger processors, and \$200K for ES&H and management.

18.2.10 Data Acquisition Electronics and Links

The BTeV data acquisition system (DAQ) must digitize and buffer all detector data at the beam crossing rate. The data is transferred from the detector subsystems to the Level 1 Buffers in the counting room (a distance of 30 to 70 meters) by optical links. Level 1 Buffers store data while Level 1 trigger decisions are being made and Level 2/3 buffers hold data while processor farms process further trigger logic. A set of large switches under control of the processors direct the data flows.

The costs of the DAQ system are based on current experience in purchasing similar systems for Run II. These costs include, \$3.2M for electronics, \$1.0M for the optical links, \$400K for installation and hardware, and \$150K for ES&H and management.

18.2.11 Level 2/3 Processor Array

The Level 2/3 Processor array consists of a large number of independent general-purpose processors (2,500 in the baseline system). They interface to the DAQ network through standard fast ethernet links and will be standard low-cost consumer PCs with minimal add-on features. They will probably run a Linux variant to reduce software costs. The links to the data acquisition system are included in the Data Acquisition subproject. This project includes mainly the processors.

The costs of this system are based on using the cost of Run II purchases as a fixed starting point and are extrapolated using a conservative model of industry trends (that is, we use the classic performance/price slope, rather than the much steeper one that has been applicable in recent years). The costs include \$2.3M for processors, \$300K for disks and network connections, \$370K for tape drives and external data connections, and \$20K for ES&H and management.

18.2.12 Analysis and Simulation Facilities

These costs occur within the Computing Division and are discussed in the section below on Offline Computing Cost Estimates.

18.2.13 Controls/Monitoring and Timing

The goal of the monitor and control system is to provide access to all electronic systems in the BTeV experiment via a single host computer. It integrates the configuration, firmware management, monitoring, timing, and diagnostics functions into a single system. It is implemented as a tree network of links and PC processing nodes.

The costs of this monitor/control system are based on similar systems recently designed and built at Fermilab. These costs include \$1.3M for electronics, \$410K for rad hard ICs, and \$140K for ES&H and management.

18.2.14 Control Room Electronics and Equipment Infrastructure

The control room information infrastructure necessary for personnel to run the experiment and the electronics tying all the disparate pieces together into a coherent system are included in this section. The usual consoles and monitor screens are included, along with some common electronics items. Two accelerator interfaces are provided, one in the control room and a duplicate in the pit.

The costs of this system are based on similar systems recently designed and built at Fermilab. These costs include \$470K for electronics, \$570K for infrastructure, and \$120K for ES&H and management.

18.2.15 Control, Monitoring and Event Readout Software

This section includes the software and hardware framework to control and monitor the data flow in the data acquisition system. It also includes Test Stand software and Control/Monitoring and Timing System software.

Cost estimates for these systems are based on experience with similar software projects at Fermilab. Contingencies are small because nothing in this system is considered risky technically. The costs include, \$1.5M for DAQ software, \$320K for test stand software, \$400K for slow controls, and \$410K for ES&H and management.

18.2.16 Algorithm and Other Software and Integration Facilities

These costs occur within the Computing Division and are discussed in the section below on Offline Computing Cost Estimates.

18.2.17 Test Stands and Test Equipment

The BTeV Test Stands and Test Equipment are used to facilitate development and testing of the individual components of the entire system. The BTeV Test Stand will be a convenient and efficient way to perform component level debugging throughout the entire design and development stages and will be built to identical specifications, yet contain the flexibility the user needs to customize their test stand. The test stand will be based on a PC or workstation that can accept standard PCI-based plugin cards.

The major components of the BTeV Test Stands and Test Equipment are mostly vendor supplied stock items. The costs for these items are based on either current catalog prices or on purchase orders from recently purchased equipment. The costs include \$950K for test stand hardware, \$450K for test equipment, \$105K for test stand software, and \$120K for ES&H and management.

18.2.18 Unassigned

WBS level 1.18 is unassigned.

18.2.19 System Installation, Integration Testing and Commissioning

This section includes those items that have to do with bringing together the various elements of the BTeV Detector and making them operate in concert with each other. Some of the tasks included here are: environmental safety and health (ES&H), and the management of the system installation and commissioning.

The cost estimates for this item are almost entirely labor. The labor estimates are based on discussions with personnel from CDF and D0. A uniform contingency of 25% was added to the time estimates. The costs include \$850K for system installation, and \$300K for ES&H and management.

18.2.20 BTeV Project Management

The project management section includes the project office, its staff, and its expenses. It is assumed that a Project Manager, Deputy Project Manager, Project Mechanical Engineer, Project Electronics Engineer, Project Safety Officer, and an Administrative Assistant/Project Budget Officer are included as well as a travel budget and consultant expenses.

The costs for BTeV Project Management include \$2.9M for the BTeV project office, \$300K for project management by physicists, \$500K for external reviews and consultants, and \$200K for documentation and software.

18.3 The Offline Computing Cost Estimate

The cost of development for the data acquisition software is included in the detector portion of the project. Here we present cost estimates for the acquisition and commissioning of the data analysis hardware and the development of the offline software. The software includes both the infrastructure and framework for the reconstruction, data access, and physics analysis as well as the development of the reconstruction and physics analysis algorithms. While we expect that physicists and software professionals will collaborate closely in both parts of the effort, we expect that the infrastructure and framework will have a large component of computing scientists and software professionals while the algorithm and analysis development will have a large component of physicists.

The costs are driven by the amount of data recorded by the experiment, which is discussed in detail in this document, the number of processing steps, the processing time per step, the number of parallel analyses and the number of data analysts. The efforts on the trigger and the intense simulation efforts, along with the group experience with analysis of some of the largest datasets recorded in HEP so far form part of the basis for these estimates. Experience with Run 2 and Computing Division experience and tracking of trends form the other major input.

18.3.1 Analysis and Simulation Facilities

The simulations, reconstructions, and analyses needed to produce physics results from the BTeV data will be carried out on farms of PCs. The costs in this section are based on the assembly, coding, and operation of the PC farms recently built for CDF and D0. The costs include \$1.3M for analysis computing, \$2.9M for data archiving, and \$600K for desktop systems.

18.3.2 Algorithm and Other Software and Integration

This section addresses the costs associated with developing the software needed to translate the raw data stream into reconstructed HEP event samples. The software costs associated with the efficient storage and retrieval of data, pattern recognition algorithms, code management, and event visualization tools are included. The costs include $2.9M for algorithm and code development, and $3.5M for software tools and code management.

18.4 Cost Summaries

18.4.1 Detector Cost Summary

The total of the baseline cost estimate is 105 M$, as detailed in Table 18.1.

Table 18.1: Baseline BTeV Detector Cost Estimate ($)

Item	Cost BTeV Baseline	Comment
Magnets,beampipes	1.80 M	
Pixels	14.25 M	based on CMS and ATLAS projections
RICH	17.14 M	based on HERA-B RICH
EM Calorimeter	21.02 M	based on $PbWO_4$ from CMS
Muon	6.72 M	
Straw Tubes	12.14 M	based on ATLAS staw tubes
Silicon Strips	5.10 M	based on Run II silicon
Trigger Level 1	6.20 M	based on 3200 DSP processors
DAQ+links	4.82 M	based on 2500 processors, 20 tape drives
Level 2/3	2.95 M	
Controls/timing	1.97 M	
Control room	1.16 M	
DAQ software	2.87 M	
Test stands	1.62 M	
Installation, commissioning	1.45 M	
Project management	3.86 M	
Total	105.07 M	

18.4.2 Computing Cost Summary

The total of the baseline cost estimate of the computing hardware and software, 12.4 M$, is detailed in Table 18.2.

Table 18.2: Preliminary BTeV computing cost estimate ($)

Item	Cost (2 arms)	comment
Hardware	5.3 M	based on industry trends
Software Dev.	7.1 M	includes 50% contingency
Total	12.4 M	